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Precipitation Extremes: Considerations for Anthropogenically-forced Future Changes

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Probable Maximum Precipitation (PMP)

- Definition: Theoretically **greatest depth of precipitation** for durations of hours-weeks under modern meteorological conditions
- **Design** of long-lived civil engineering structures (e.g. **dam spillways**).
- PMP- a physical estimate of the **upper bound** of extreme precip, a **"10,000 year" recurrence** based on Probable Maximum PW

Topics

- **Observed trends in very extreme** precipitation events
  - Timing of largest daily events
- **Global climate Model** simulations
  - End-of-Century; high emissions scenario
- **Dynamical considerations** and implications for modeling

Trends

- Period of Analysis: 1951-2015
- **Largest daily event** in analyzed record: sample size challenge
- **3843 U.S. stations** with less than 10% missing data over that period
- Annual time series of **number of stations** in each year experiencing their **largest event**

Trends

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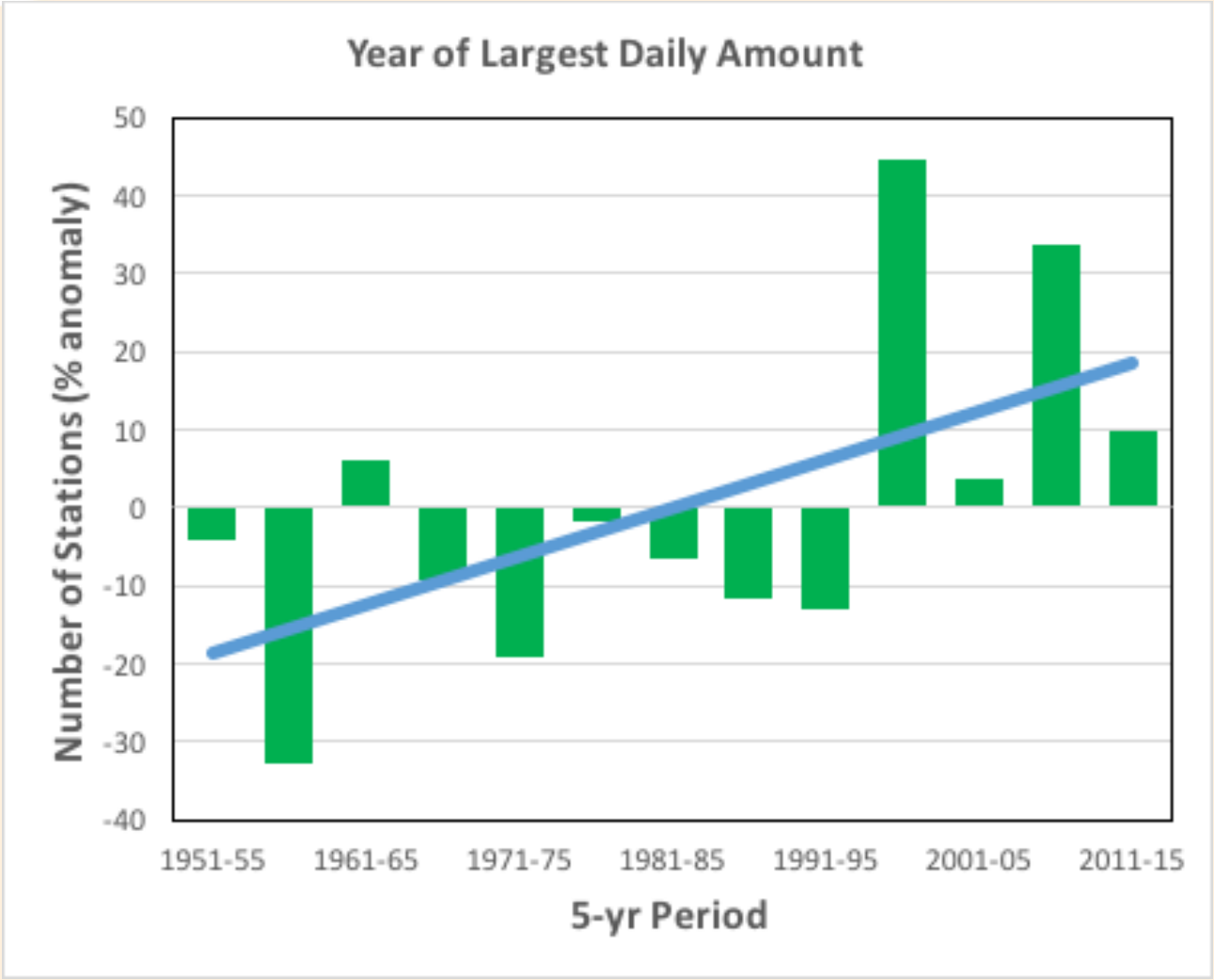

3843 U.S. stations

Climate Modeling

- Will show results from **global** (CMIP5) and **regional** (CRCM) models
- **CMIP5 analysis** provides a global perspective
  - But, global climate model **spatial resolution is too coarse** to accurately simulate **details and intensities** of extreme precipitation-producing meteorological systems

Global Climate Modeling

- **Projections for 2071-2100** compared to 1971-2000 under a **high emissions** scenario (RCP 8.5)
- **30-yr maximum** daily precipitation
- 30-yr maximum 12-hr **precipitable water**
- Average of seven CMIP5 models

Global Climate Modeling

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Kunkel, K.E., T.R. Karl, D.R. Easterling, K. Redmond, J. Young, X. Yin, and P. Hennon, 2013: **Probable maximum precipitation (PMP) and climate change**. *Geophys. Res. Lett.*, **40**, doi:10.1002/grl.50334.

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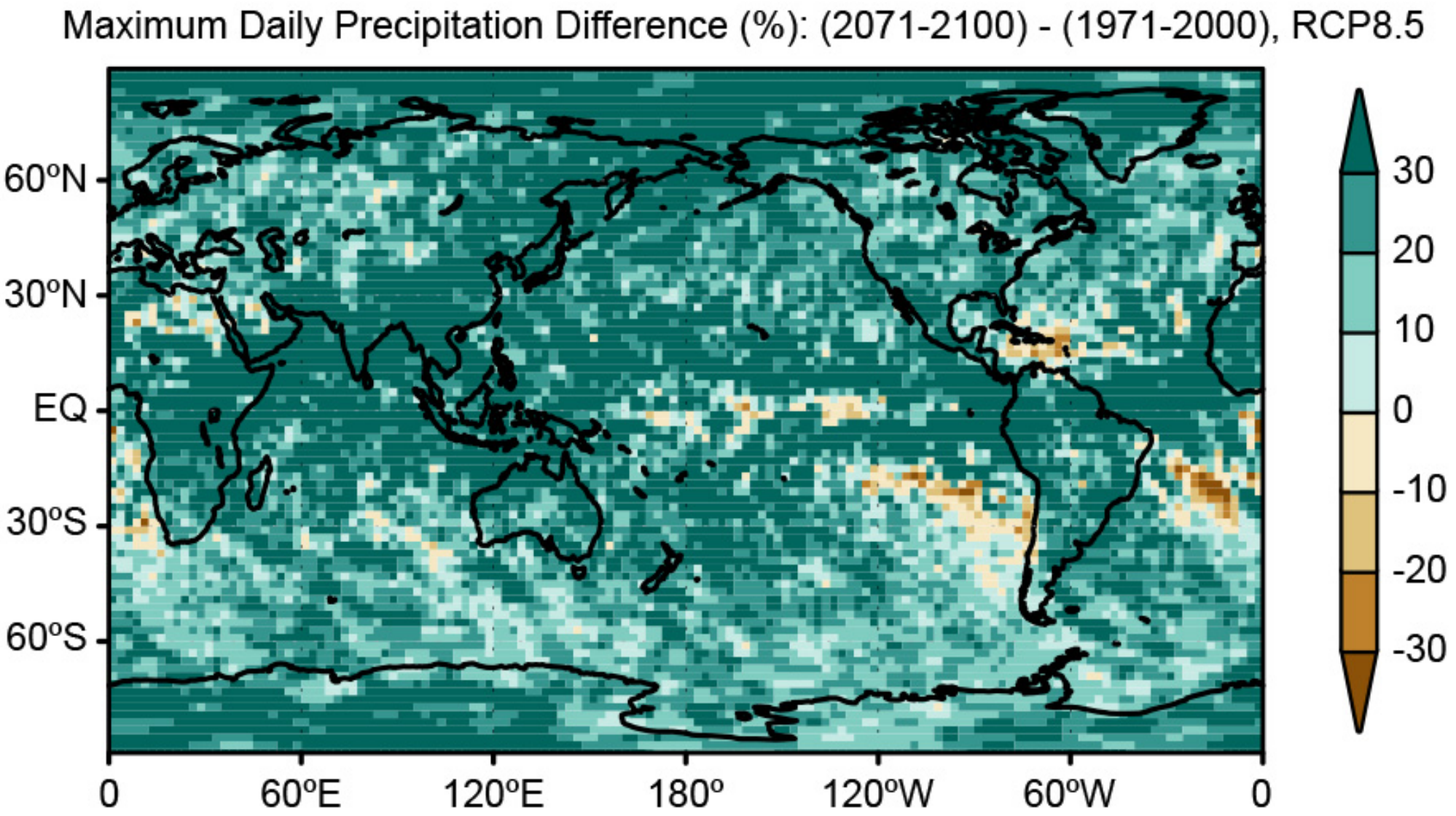
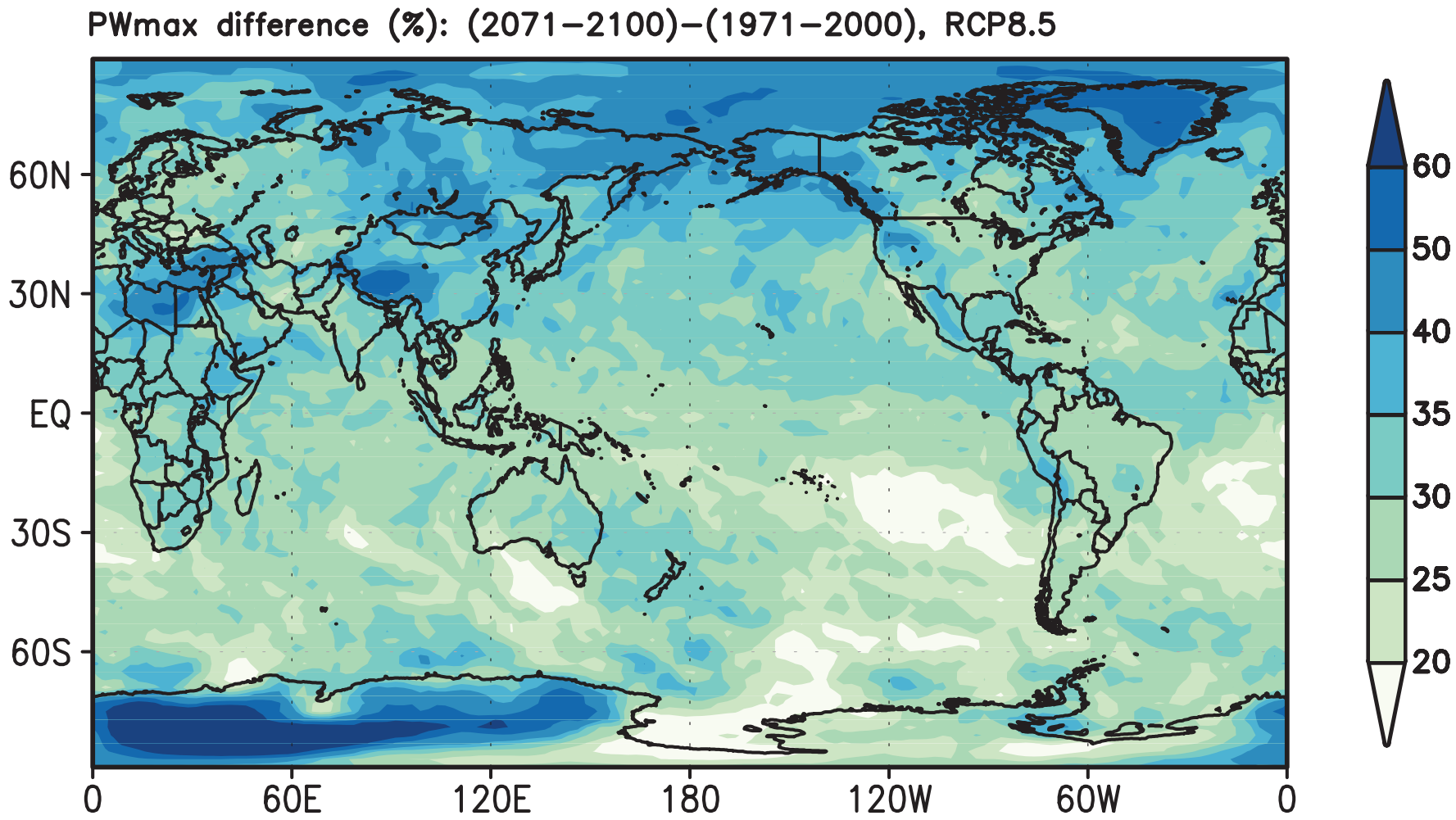
30-yr Maximum Daily Precipitation

Projected 100-yr trends



30-yr maximum precipitable water

Projected 100-yr trends



Meteorology of Observed Extremes

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- Period of analysis: 1908-2009
- 932 stations
- Approximately **20 largest daily events** examined for each station

Meteorology of Observed Extremes

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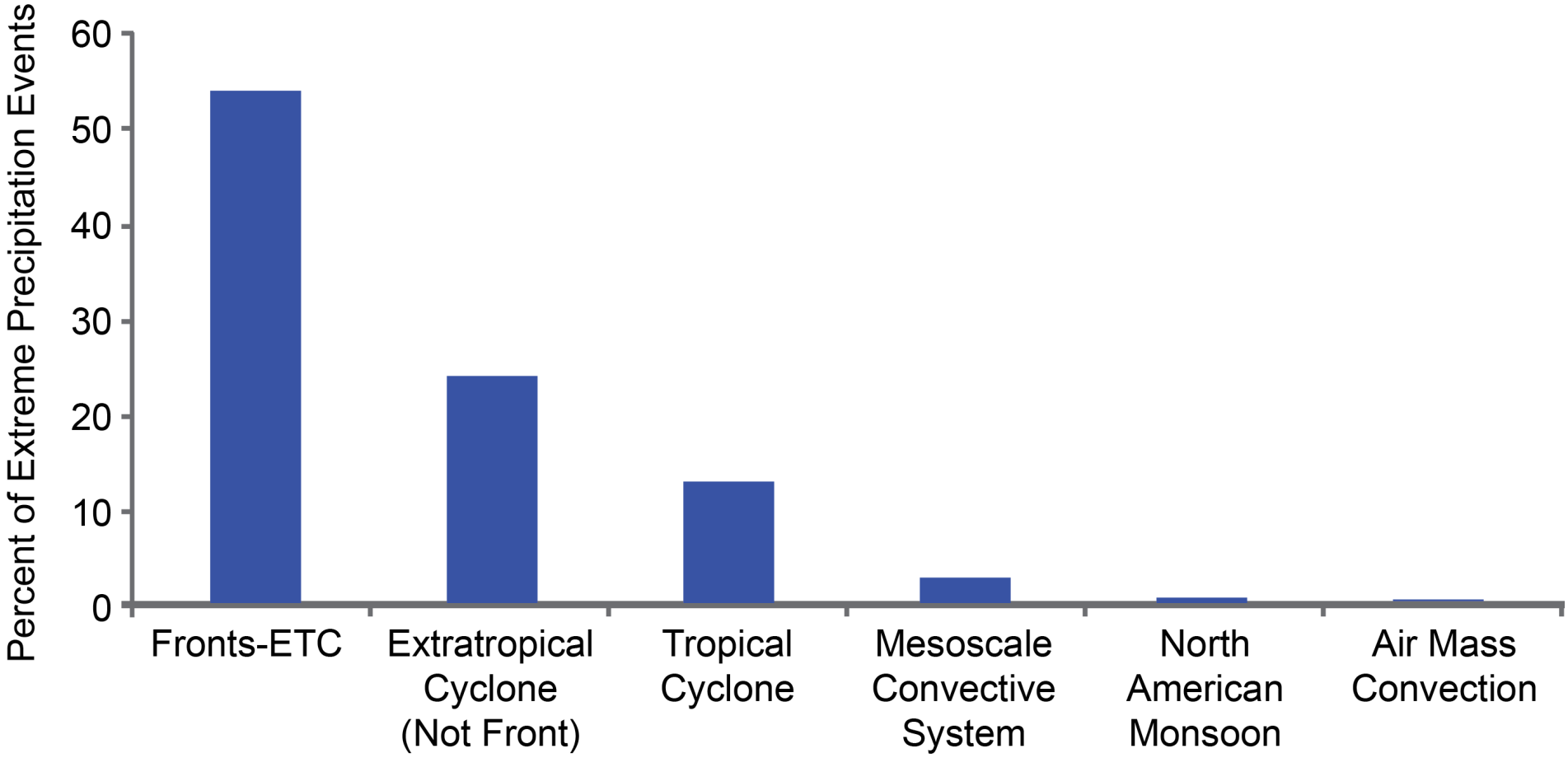
Dominated by large systems



Meteorology of Extreme Events

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- Results are similar for subset of the **top-ranked event** at each station except:
  - **Higher** fraction of **tropical cyclone** events
  - **Higher** fraction of **air mass convection** events
  - **Lower** fraction of **mesoscale convective systems** events

Dynamical considerations

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- To first order, **PMP** design value **changes** may follow temperature increases according to **Clausius-Clapeyron**
- Are there **dynamical** process that may **amplify or suppress** such changes?
- Can state-of-the-art regional climate models **adequately simulate** the relevant **dynamical processes**?

Dynamical considerations

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- Tropical cyclones
  - Dynamics
    - **The ultimate danger**, capable of producing PMP values for a wide range of timescales: hours to days
    - PMP TC rains are most likely for **stationary or slowly moving** storms during periods of reduced wind intensity
    - PMP TC may be **enhanced** as slowly TC **track is is over gently mountainous** regions
  - Modeling
    - Time scale of hours: need very fine 3D grid to **resolve mesoscale convective bands**
    - Hours to days: need a fine-grid regional model with a **minimum of convective parameterization** and realistic boundary conditions

Dynamical considerations

- Extratropical cyclones
  - Dynamics
    - Time scales of local duration: **several hours – days**
    - **Stationary wind** pattern of moist inflow
    - Often, a **stationary front** in the vicinity with gradients of moisture and temperatures
    - Often, persistent moist inflow into **upslope** portions of high mountains
  - Modeling
    - High resolution **NWP model**
    - Must resolve **mesoscale features** in frontal zones and mountain complexes
    - Capable of resolving **sub-synoptic** and some **mesoscale physics** of precipitation

Dynamical considerations

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- Mesoscale convective systems
  - Dynamics
    - Organized by **larger scales of winds or topography**: time scales of hours-1 day
    - Stationary mesoscale organization of **"clumped" convective storms**, especially focused by topography
    - Moving mesoscale convective elements **"training"** along stationary wind pattern
  - Modeling
    - Mesoscale models of high resolution (1 km) and **accurate convective physics**
    - **Nesting** within a regional model

Dynamical considerations

- Air mass convection
  - Dynamics
    - Time scales: **minutes – 2 hrs**
    - Sustained intense convection cell imbedded in moist, unstable air mass with **light winds**
    - **Localized "anchor"** keeps it stationary
  - Modeling
    - Highest resolution **(100m) convection** model
    - Accurate sensitivity to **topography, local surface inhomogeneities**

Conclusions

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- **Upward trend** in U.S. in the occurrence of the **largest** daily precipitation **events**
- **Diversity** of **weather system types** can cause the very largest precipitation events
- The **dynamical** considerations and climate **modeling challenges** are **different** depending on duration and type

Regional Climate Model

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- Much higher spatial resolution (**45 km vs ~150 km**)
- **Better process simulation** of meteorological systems and better representation of topography, water bodies, and other land properties
- **More scientific confidence** in simulation results (although simulation is constrained by GCM-provided lateral boundary conditions and associated errors in those)

Regional Climate Model analysis

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- We pooled **5** (same forcings, different initial conditions) **30-yr simulations** (Canadian RCM nested within time-varying Canadian GCM)
- Treated as the **equivalent of a 150-yr** simulation (present and future)
- Calculated the **average annual maximum precipitation** at each grid point
- **Ratio** of the 2041-2070 value to the 1971-2000 value

Regional Climate Model Analysis

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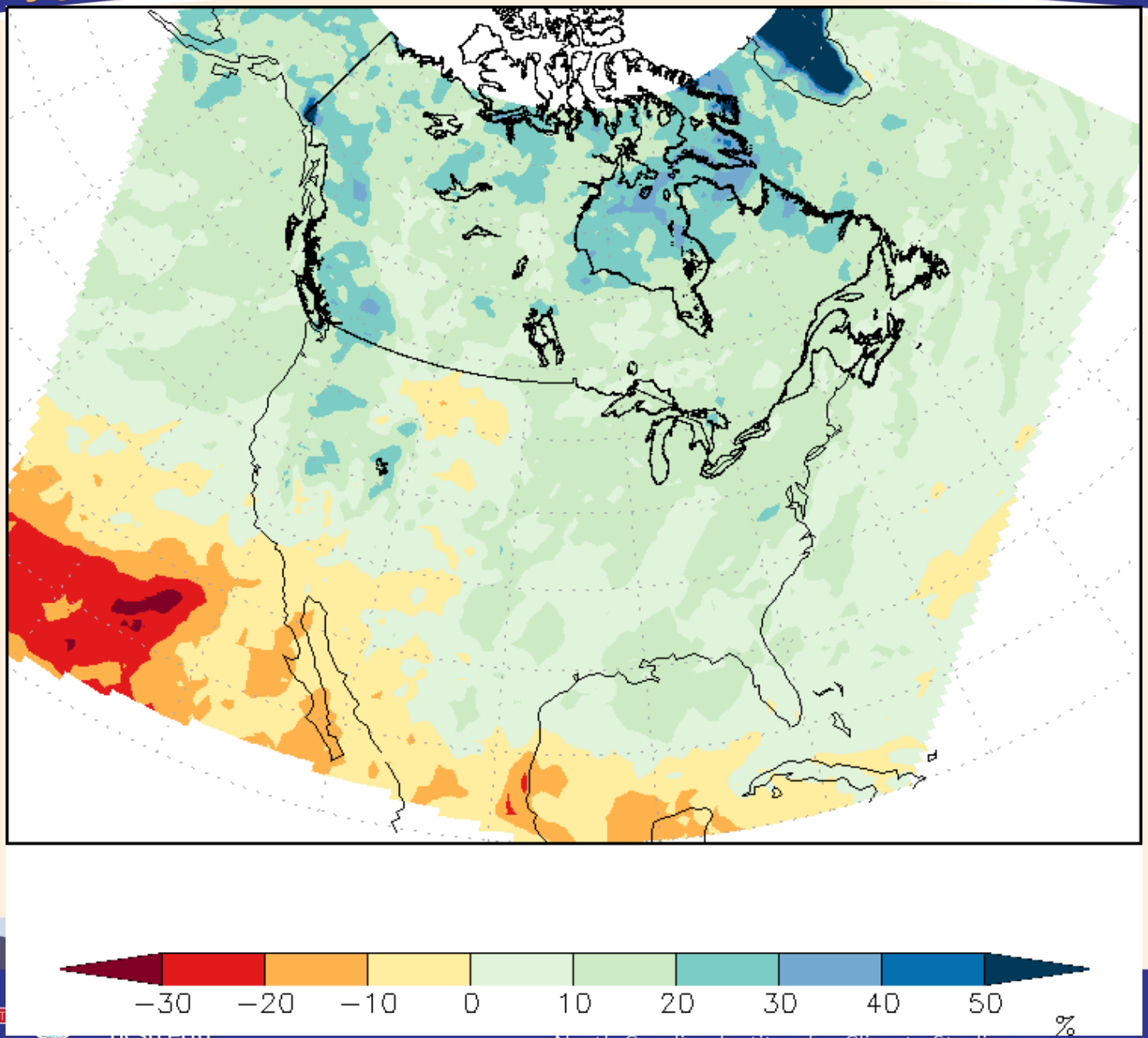

Regional Climate Model analysis

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- Future **increase** in annual maximum precipitation at **mid and high latitudes**, little change or decreases at subtropical latitudes
- Annual maximum used as metric to establish **robust statistical results**
- But, how does this translate to PMP changes? **Not obvious**!

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EXTRA SLIDES